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B15

A Preliminary Study to Determine the Feasibility of Medium Pressure Mercury Lamps for Disinfecting Low Quality Wastewaters.

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INTRODUCTION

During dry weather most wastewaters receive some form of chemical or biological treatment to remove organic and inorganic constituents and then these effluents are disinfected to protect users of the receiving waters. It is only during periods of rainfall that significant quantities of effluents such as stormwater runoff and combined sewer overflow are allowed to flow into watercourses with little or no treatment. Combined sewer overflow is the result of joint wastewater and surface runoff collection systems. These combined sewer systems are prevalent in older areas of most municipalities. These microbiologically contaminated waters have contaminated raw water supplies and swimming areas throughout North America. The closure of swimming areas is a great inconvenience for everyone and results in a loss of revenue for those involved in tourism.

Programs to alleviate the situation include the separation of combined sewers which is very expensive, methods of reducing the volume and frequency of overflows, and methods of improving the quality of the storm runoff. It is this latter aspect where the use of medium pressure mercury ultraviolet lamps was investigated for the purpose of disinfecting low quality wastewaters.

Previous studies (Scheible, 1985 and Zukovs, et al. 1986) have shown that combined sewer overflow (CSO) can be disinfected with low pressure mercury lamps but the capital cost of the system is very high compared to chlorine because of the large number of lamps. The high cost is a result of the high flow rates and long retention times which are required to obtain a three logarithm reduction in the number of fecal coliforms.

A medium pressure mercury lamp has a much higher intensity per unit of arc length compared to a low pressure mercury lamp. A low pressure mercury lamp which is normally used for the disinfection of liquids has a UV output of approximately 0.2 watts per centimeter of arc length at a wavelength of 254 nm. The output of UV light is almost monochromatic and within six nanometres of the optimum wavelength for germicidal action. Medium pressure mercury lamps have an average UV output of 9 watts per centimeter of arc length at wavelengths below 380 nm.

If all of these wavelengths below 380 nm were equally effective at killing fecal coliforms, a medium pressure mercury lamp would have 45 times as much germicidal power per centimeter of arc length. A significant decrease in the number of UV lamps would result in a much lower capital cost which could make UV irradiation of low quality wastewaters an economically viable process.

The study had three phases. The first phase determined the dose of UV light which was required from a low and medium pressure mercury lamp to disinfect a series of different quality wastewaters. The second phase looked at the total UV output of low and medium pressure mercury lamp so that a pilot system could be built. The third phase involved the testing of a medium pressure lamp system with three different waterlayers to determine the economic feasibility of the process.

PHASE 1: DIRECT COMPARISON OF THE LOW AND MEDIUM PRESSURE MERCURY LAMPS WITH THE LOW QUALITY WASTEWATERS.

1. Purpose

This phase of the study compared the monochromatic light (254 nm wavelength) of the low pressure mercury lamp to the broader spectrum of the medium pressure mercury lamp. The bioassay method of Qualls and Johnson (1983) was used to make this comparison. The bioassay uses a collimated beam of light to irradiate a volume of stirred wastewater.

Two collimated beams were adjusted so that a UV sensor which was only sensitive to light around a wavelength of 254 nm showed that the beams were equal in UV output. The additional wavelengths in the spectrum of the medium pressure lamp should show up in the survival curves of the fecal coliforms in the various wastewaters. These survival curves can then be used to compare the two types of mercury lamps. The dose of UV light was adjusted so that a three logarithm kill or 200 fecal coliforms per 100 mL was reached in every wastewater.

2. Materials and Methods

Samples of raw wastewater after the comminuting devices, raw wastewater after primary settling and secondary treated wastewater were obtained from the Greenway Wastewater Treatment Plant in London, Ontario, Canada. Samples of raw water after the comminuting devices were also obtained from the wastewater treatment plant in Ingersoll, Ontario, Canada.

Various strengths of CSO were prepared by mixing secondarily treated wastewater so it contained 13.5, 25 and 50 percent raw effluent.

The bioassay method of Qualls and Johnson (1983) was modified so that the medium and low pressure mercury lamps could be compared. Two collimated beams (Figure 1) were set up side by side so that the same day's samples was irradiated with the medium and low pressure mercury lamps.

Both light sources were set at 200 microwatts/cm^2 at the liquid surface with an International Light 1500 Radiometer with an SEE 240 sensor (International Light Inc, Dexter Industrial Green, Newburyport, Massachusetts, USA).

A single (50mL) of wastewater was measured into the irradiation chamber shown in Figure 1 and continuously stirred during the exposure to UV light. A series of exposure times was used for each wastewater. The wastewater was 2 centimeters deep.

Unirradiated samples were stirred to determine whether the suspended solids were being broken up by the magnetic stirring bar.

Each sample of wastewater was analyzed for UV transmittance at a wavelength of 254 nm. Each wastewater was filtered through a 0.45 micron Gelman GN type filter and analyzed for UV transmittance at a wavelength of 254 nm.

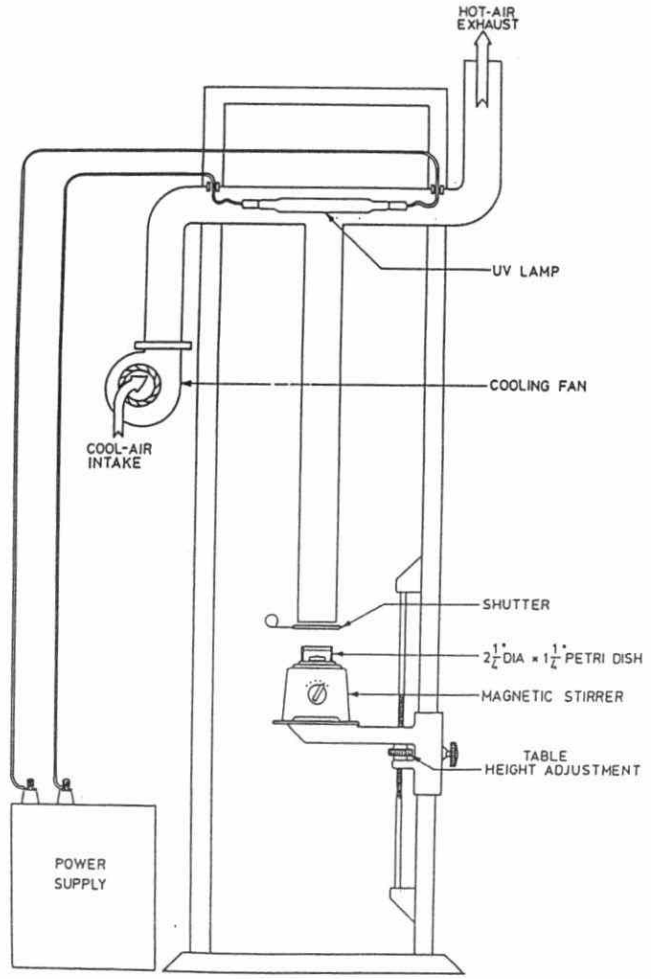


Figure 1: Schematic diagram of the collimated beam apparatus for irradiating the various wastewaters.

The total suspended solids of each wastewater was analyzed according to Method 209C in the 16th Edition of Standard Methods For The Examination of Water and Wastewater (American Public Health Association, 1985).

The fecal coliforms were measured by the membrane filtration and rota-plate method. The membrane filtration method and the media for the rota-plate method were from the (Ontario Ministry of the Environment, 1984) Handbook of Analytical Methods for Environmental Samples.

Each wastewater was tested at least five times or until consistent results were obtained.

3. Results and Discussion

The results in Table 1 show that stirring the raw, primary and secondarily treated wastewaters in the irradiation chambers had no effect on the count of the fecal coliforms. Therefore, the samples can be stirred during the irradiation without breaking up the suspended solids. This is important because the size and level of suspended solids affects the degree of disinfection which can be attained (Qualls et al., 1985).

Figure 2 to 8 and Table 2 summarize the paired testing of the low and medium pressure mercury lamps on the raw, primary, secondary and mixtures of wastewaters.

All of the kill curves are typical of that found for fecal coliforms in wastewater (Qualls et al., 1985) in that a final plateau is reached where increases in the dose of UV light has very little effect on the level of fecal coliforms. This is due to the suspended solids which protect the fecal coliforms from the UV irradiation.

Table 1: The effect of stirring the wastewater in the irradiation chambers on the level of fecal coliforms.

Wastewater	Geometric Mean Fecal Coliforms per 100 ml Time in Minutes 0	40
Raw	1.2×10^6	1.3×10^6
Primary	1.4×10^6	1.5×10^6
Secondary	1.4×10^4	1.4×10^4

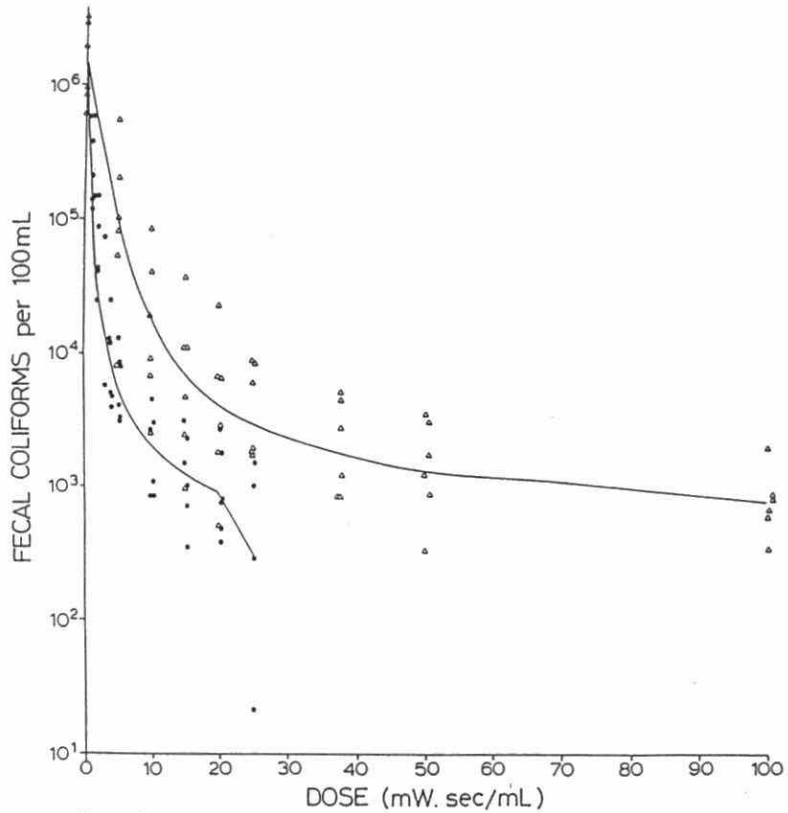


Figure 2: Paired testing of the low (Δ) and medium (•) pressure mercury lamps on the raw effluent from the Greenway Wastewater Treatment Plant using the collimated beam.

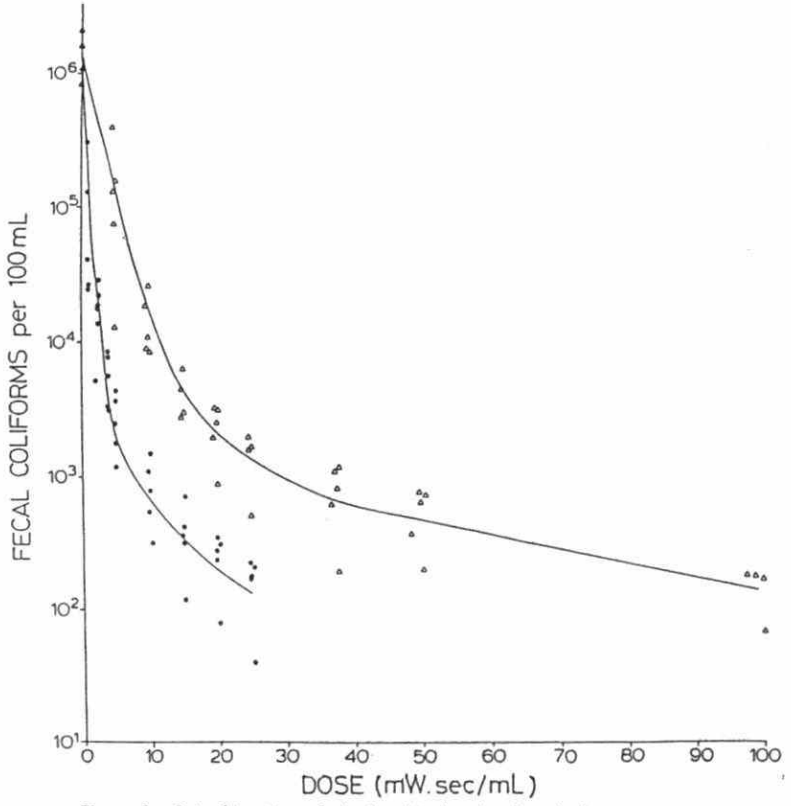


Figure 3: Paired testing of the low (Δ) and medium (•) pressure mercury lamps on the primary effluent from the Greenway wastewater treatment plant using the collimated beam.

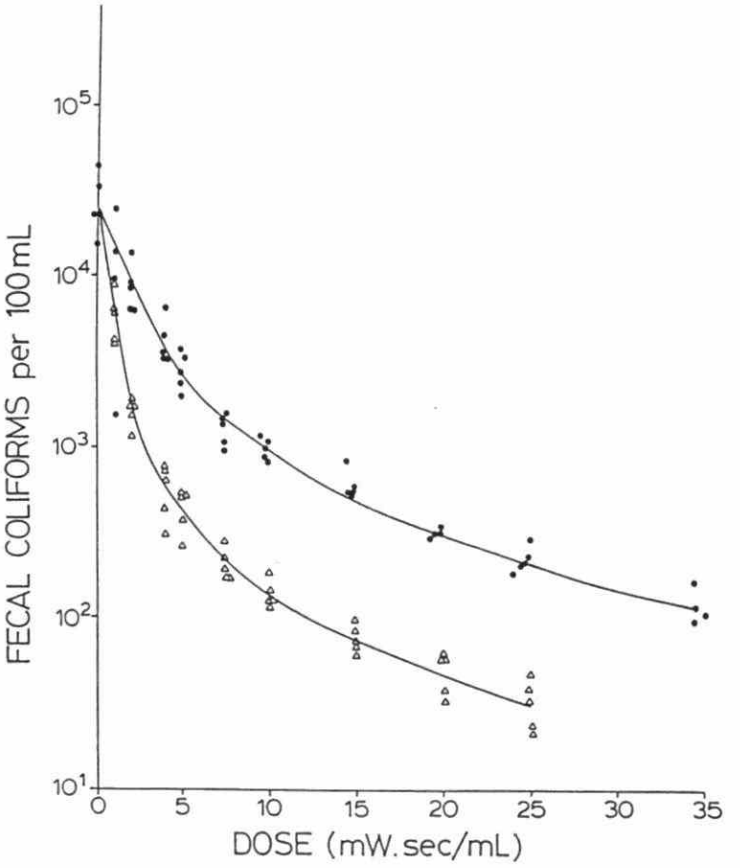


Figure 4: Paired testing of the low (•) and medium (Δ) pressure mercury lamps with the collimated beam on the secondarily treated effluent from the Greenway wastewater treatment plant.

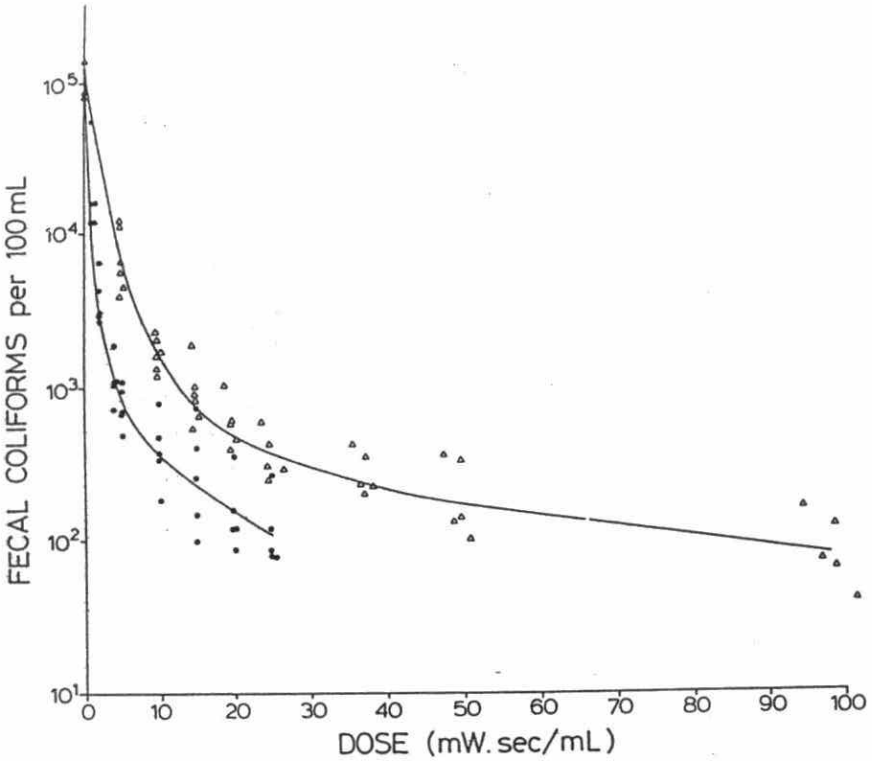


Figure 5: Paired testing of the low (△) and medium (▲) pressure mercury lamps with the collimated beam on the mixture of 12.5% raw effluent and 87.5% secondary effluent from the Greenway wastewater treatment plant.

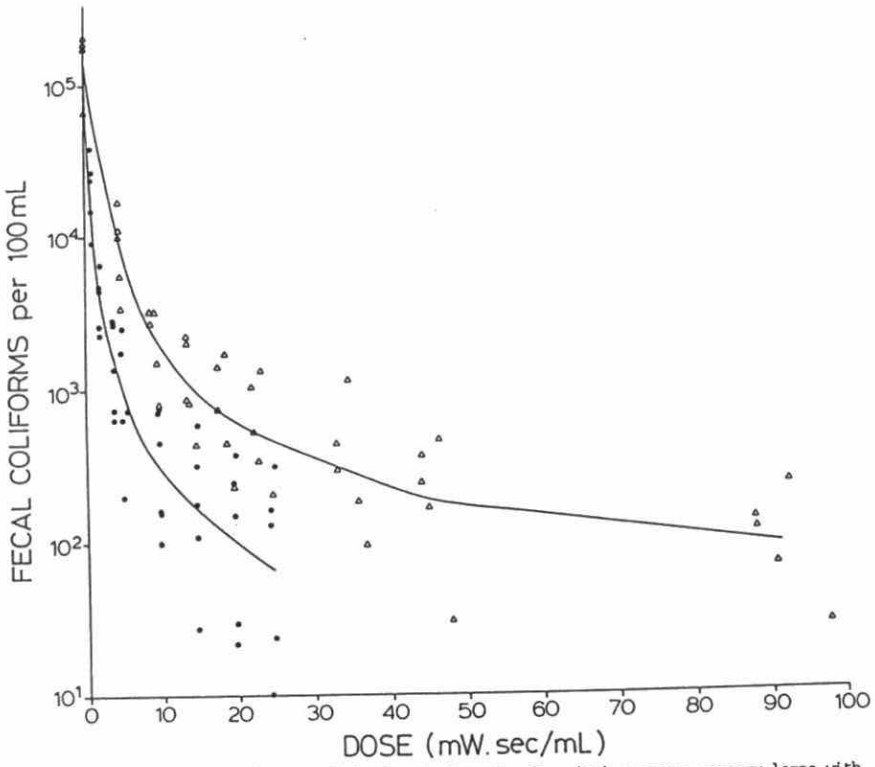


Figure 6: Paired testing of the low (△) and medium (●) pressure mercury lamps with the collimated beam on the mixture of 25% raw and 75% secondary effluent from the Greenway wastewater treatment plant.

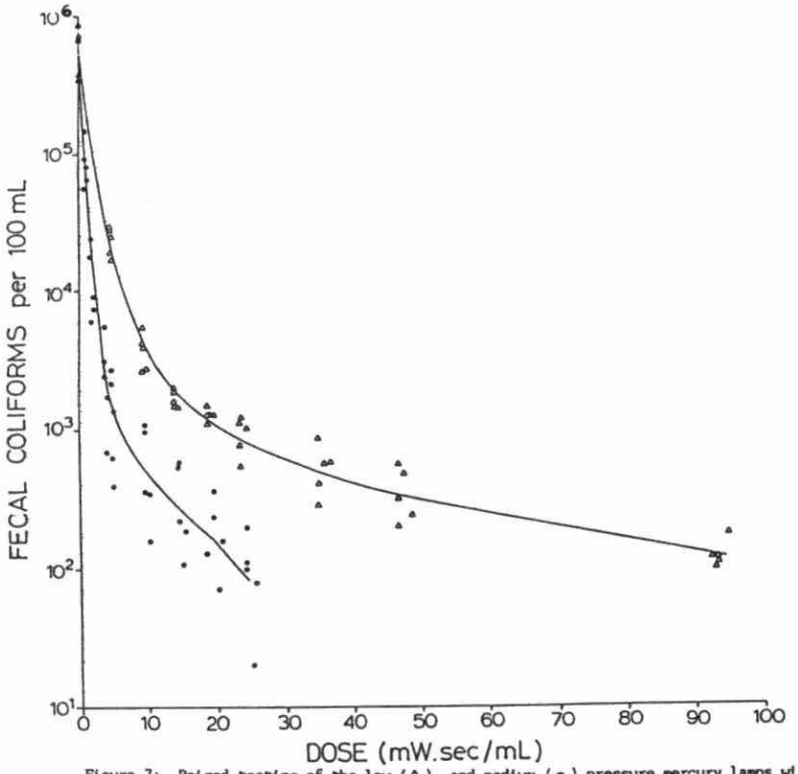


Figure 7: Paired testing of the low (Δ) and medium (•) pressure mercury lamps with the collimated beam on the mixture of 50% raw and 50% secondary effluent from the Greenway wastewater treatment plant.

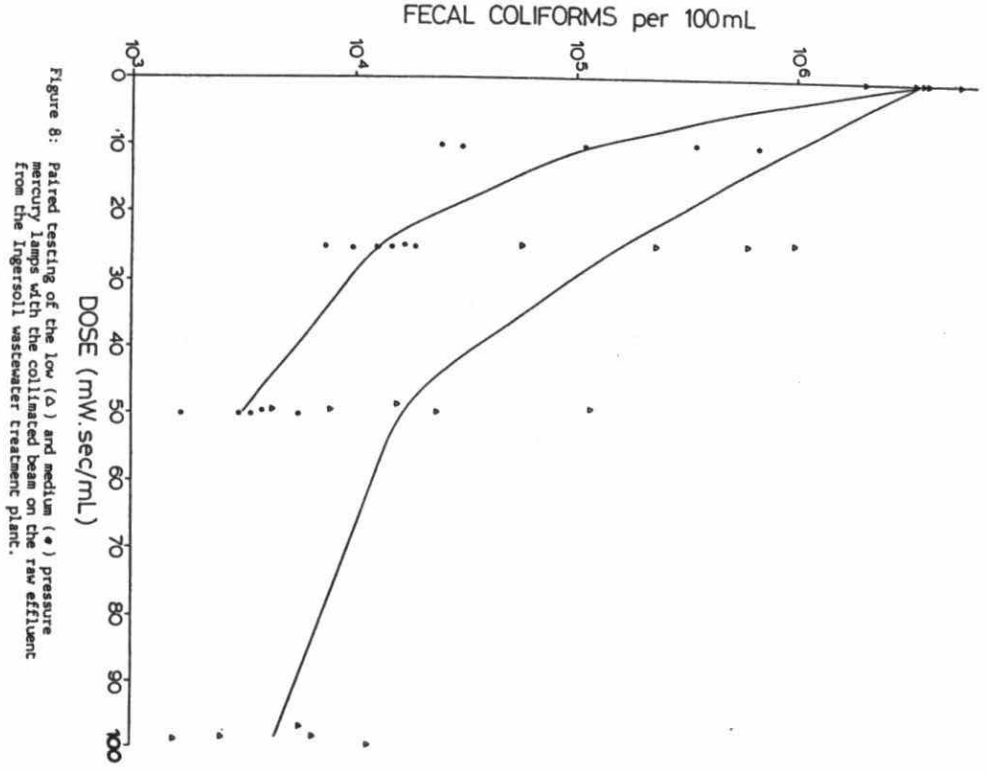


Figure 8: Paired testing of the low (Δ) and medium (•) pressure mercury lamps with the collimated beam on the raw effluent from the Ingersoll wastewater treatment plant.

Table 2: The filtered and unfiltered UV transmittance and total suspended solids of the various wastewaters and mixtures of wastewaters.

Wastewater		% Transmission 254 1 cm		Total Solids (mg/L)
		Unfiltered	Filtered	
Raw	Mean	27.7	63.7	121
	SD*	2.5	3.9	28
Primary	Mean	30.0	62.9	62
	SD	4.6	3.6	15
Secondary	Mean	71.7	77.5	13.4
	SD	0.2	0.5	0.9
12.5% Raw: 87.5% Secondary	Mean	58.9	74.1	30
	SD	2.8	2.5	10
25% Raw: 75% Secondary	Mean	57.9	75.8	35
	SD	7.8	1.3	18
50% Raw: 50% Secondary	Mean	49.2	72.5	31
	SD	7.2	3.7	10
Raw from Ingersoll	Mean	1.5	34.4	411
	SD	1.1	7.5	169

In these experiments, the maximum dose of UV light from the low and medium pressure mercury lamps was able to reduce the count of fecal coliforms in the primary, secondary mixtures of wastewaters to below 200 fecal coliforms per 100 mL. The level of fecal coliforms in the raw effluents from the two wastewater treatment plants could not be reduced to 200 fecal coliforms per 100 mL. The high suspended solids (411 mg/L) and low UV transmission (1.1%) of the raw wastewater from Ingersoll accounts for this difference. The suspended solids accounts for this difference with the raw wastewater from Greenway because the UV transmission of the filtered and unfiltered samples were almost identical for the raw and primary effluents.

As the wastewater proceeds through the Greenway wastewater treatment plant, the unfiltered UV transmission increases by 2.6 times whereas the filtered effluent only increases by 1.2 times. The level of suspended solids decreases nine fold as the wastewater goes from the raw water to the end of the secondary treatment. Therefore the increase in UV transmission is primarily due to the decrease in suspended solids.

Curves of the survival ratio versus the dose are shown in Figures 9 to 15 for the various wastewaters. From these curves and Figures 2 to 8, the dose of UV light can be obtained which produces a three log decrease in the count of the fecal coliforms or reduces the level of fecal coliforms to 200 per 100 mL. These doses are summarized in Table 3. This table shows the quantity of UV light from a medium or low pressure mercury lamp which is required to bring the level of fecal coliforms in a volume of one millilitre down by three logs or to 200 per 100 millilitres. The dose of UV light varies quite dramatically between the different wastewaters. This is a result of the differences in the level and form of the suspended solids and the UV transmission. The flow rate can be calculated using these values for the dose and knowing the total UV output of the lamp. The total UV output of the two types of lamps was determined in Phase 2.

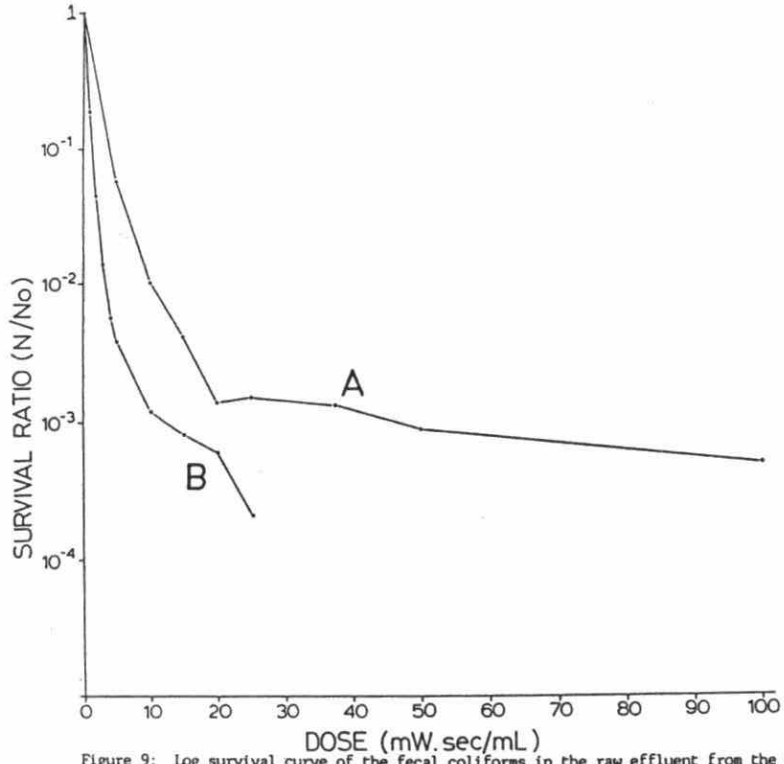


Figure 9: Log survival curve of the fecal coliforms in the raw effluent from the Greenway wastewater treatment plant after exposure to the collimated beam from the low (A) and medium (B) pressure mercury lamps.

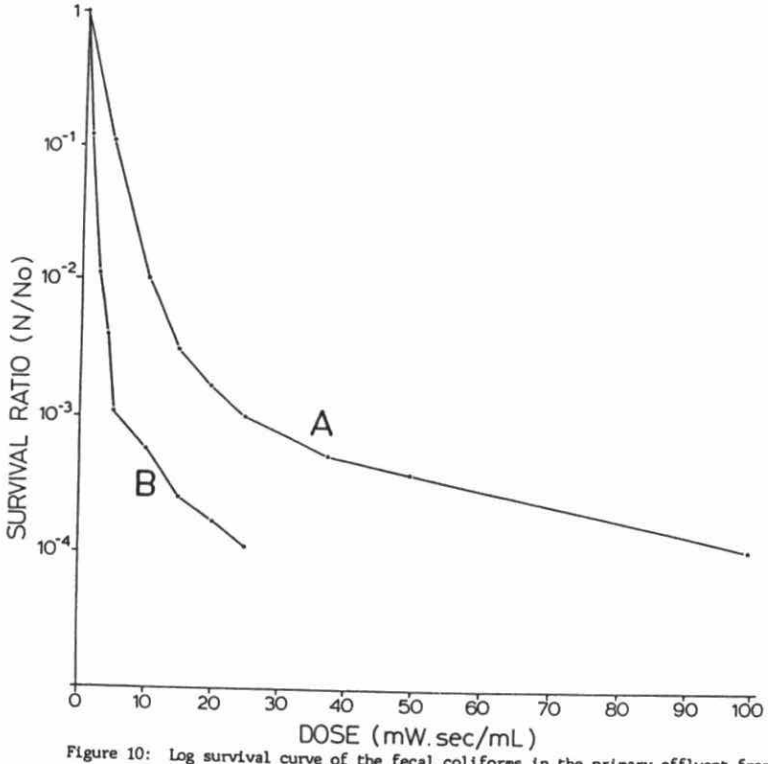


Figure 10: Log survival curve of the fecal coliforms in the primary effluent from the Greenway wastewater treatment plant after exposure to the collimated beam from the low (A) and medium (B) pressure mercury lamps.

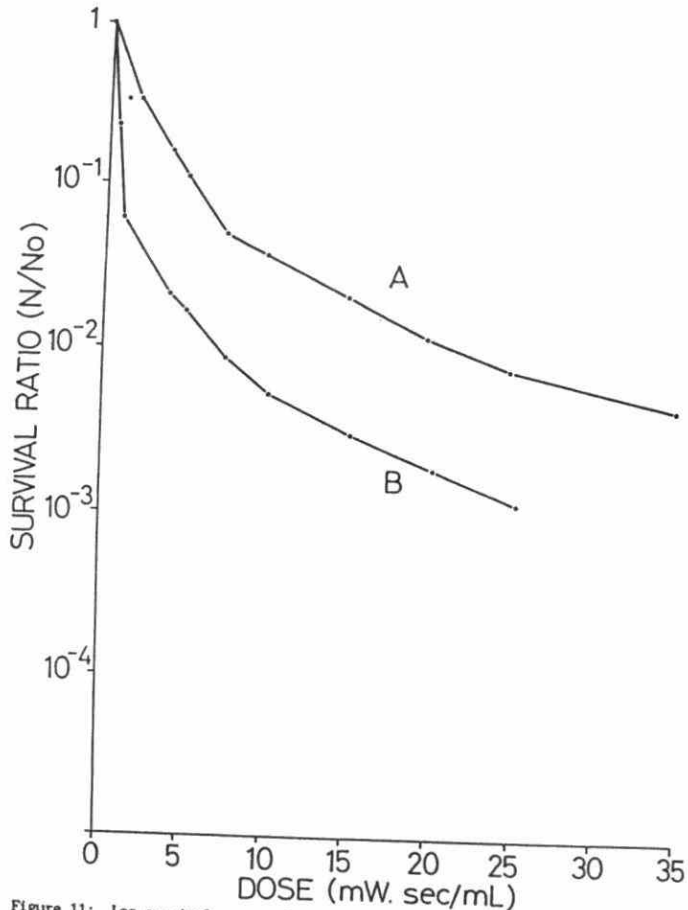


Figure 11: Log survival surve of the fecal coliforms in the secondary effluent from the Greenway wastewater treatment plant after exposure to the collimated beam from the low (A) and medium (B) pressure mercury lamps.

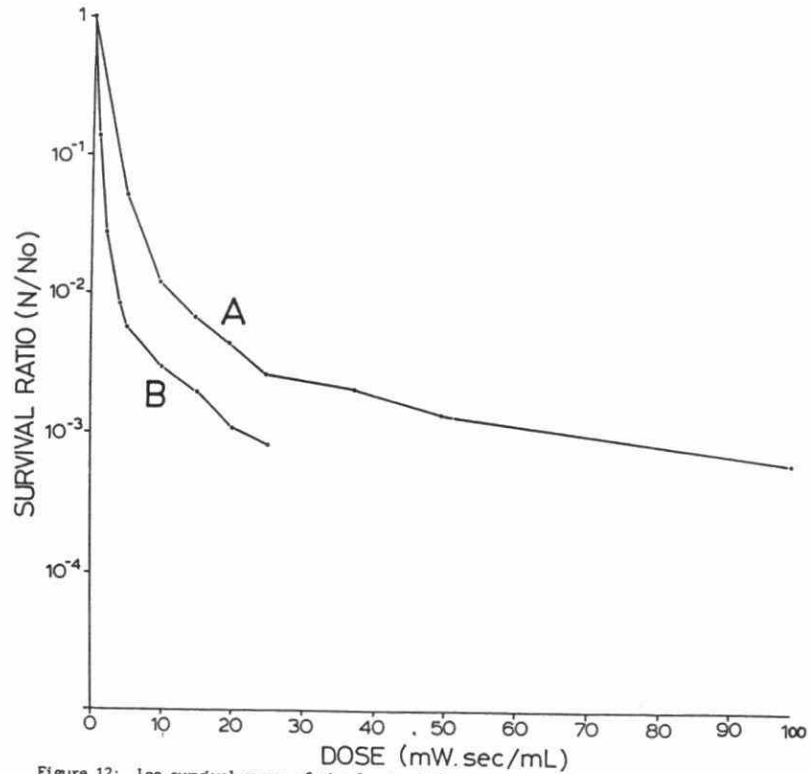


Figure 12: Log survival curve of the fecal coliforms in the mixture of 12.5% raw and 87.5% secondary effluent from the Greenway wastewater treatment plant after exposure to the collimated beam from the low (A) and medium (B) pressure mercury lamps.

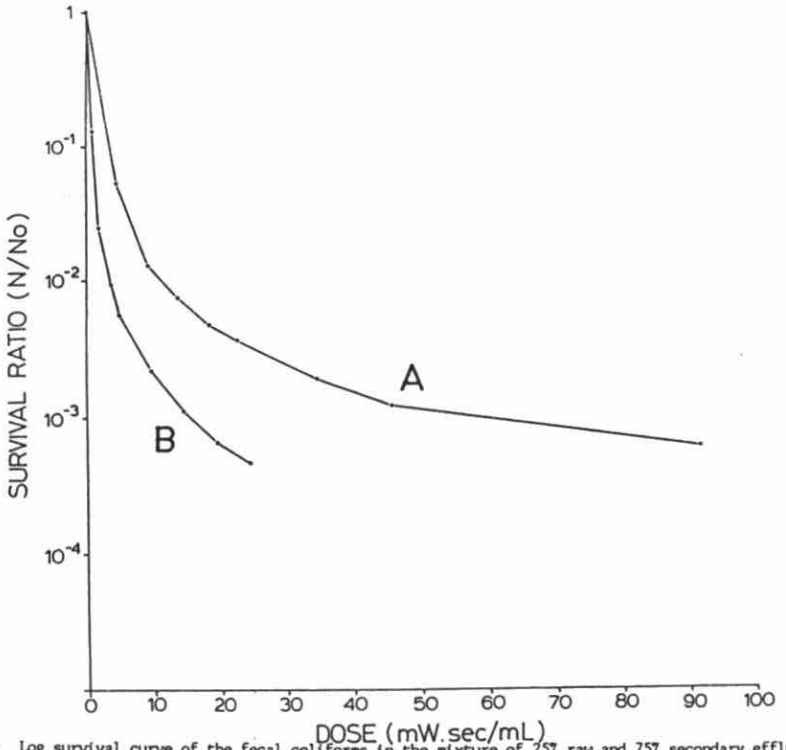
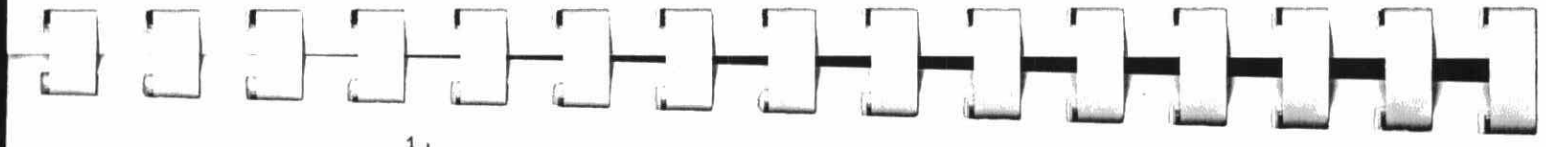


Figure 13: Log survival curve of the fecal coliforms in the mixture of 25% raw and 75% secondary effluent from the Greenway wastewater treatment plant after exposure to the collimated beam from the low (A) and medium (B) pressure mercury lamps.



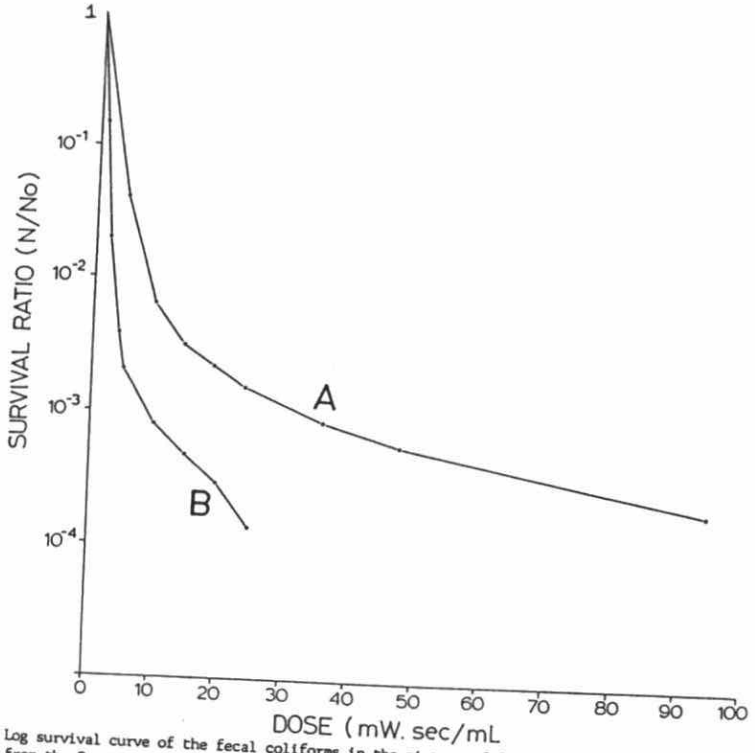


Figure 14: Log survival curve of the fecal coliforms in the mixture of 50% raw and 50% secondary effluent from the Greenway wastewater treatment plant after exposure to the collimated beam from the low (A) and medium (B) pressure mercury lamps.

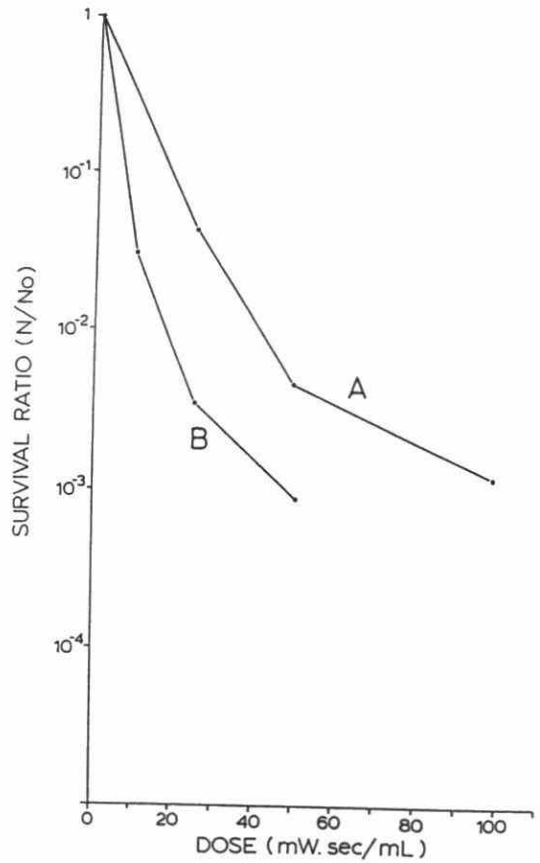


Figure 15: Log survival curve of the fecal coliforms in the raw effluent from the Ingersoll wastewater treatment plant after exposure to the low (A) and medium (B) pressure mercury lamps.

Table 3: The dose of UV light from the medium or low pressure mercury lamp which produces a three log decrease in the count of fecal coliforms or reduces the count of the fecal coliforms to 200 per 100 ml.

Wastewater	Fecal Coliform Limit	Dose ($mW.sec.mL^{-1}$) Medium Pressure Lamp	Low Pressure Lamp
Raw	3 Log Decrease	13	41
	200 per 100 mL	Not Reached	
Primary	3 Log Decrease	6	25
	200 per 100 mL	21	85
Secondary	3 Log Decrease	Not Reached	
	200 per 100 mL	6	25
12.5% Raw:87.5% Secondary	3 Log Decrease	22	69
	200 per 100mL	27	83
25% Raw: 75% Secondary	3 Log Decrease	16	56
	200 per 100 mL	14	43
50% Raw: 50% Secondary	3 Log Decrease	9	32
	200 per 100 mL	18	71
Raw Ingersoll	3 Log Decrease	49	102
	200 per 100mL	Not Reached	

The ratios of the dose of UV light from the low and medium pressure lamps for the various wastewaters are shown in Table 4. For the Greenway wastewaters and mixtures of wastewaters the ratio is 3.6 (Standard Deviation = 0.5) and it is consistent between the various types of wastewaters whereas the ratio for the raw effluent from Ingersoll is 2.1 Because the medium pressure mercury lamp has a much broader spectrum of germicidal light, this ratio may be very specific for each effluent depending upon its absorption spectrum. The raw effluent from Ingersoll has a very high iron content due to the presence of a wire manufacturer. Iron readily absorbs UV light from the low and medium pressure mercury lamps.

4. Conclusions

1. Stirring the irradiation chambers had no effect on the level of the fecal coliforms in the raw, primary or secondary effluent from the Greenway wastewater treatment plants. Suspended solids were not being broken up so the results of the irradiation should not be influenced by the release of fecal coliforms from particles.

2. Suspended solids in the Greenway effluents have the greatest effect on changes in the UV transmission as the wastewater proceeds through the plant.

3. Each type of wastewater requires a different dose of UV light to reach the required level of disinfection. This is a result of the UV transmission and suspended solids and the relationship of the fecal coliforms with these particles. To properly size a UV system for CSO, a series of survival curves should be prepared using the method described in this report.

4. When each watt of UV light from a medium pressure mercury lamp was measured with an IL 1500 Radiometer with a SEE240 sensor, it was equivalent to 3.6 watts of UV light at a wavelength of 254 nm from a low pressure mercury lamp when the wastewater was from the Greenway Wastewater Treatment Plant.

Table 4: The ratio of the doses of UV light from the low and medium pressure mercury lamps which were required to reach a three log decrease or 200 fecal coliforms per 100 mL.

Wastewater	Ratio of Dose: Low Pressure Lamp / Medium Pressure Lamp	
	Three Log Decrease in Fecal Coliforms	200 Fecal Coliforms per 100mL
Raw	3.1	-
Primary	4.2	4.0
Secondary	-	4.2
12.5% Raw: 87.5% Secondary	3.1	3.1
25% Raw: 75% Secondary	3.5	3.1
50% Raw: 50% Secondary	3.5	3.9
Raw Ingersoll	2.1	-

PHASE 2: TOTAL GERMICIDAL OUTPUT OF THE LOW AND MEDIUM PRESSURE MERCURY LAMPS

1. Purpose

The objective of this phase of the project was to determine and compare the total germicidal output of the low and medium pressure lamps. This would allow an economic comparison of the two lamps and it will also provide the information which is required for the design of the medium pressure reactor vessel in Phase 3.

2. Materials and Methods

The point source summation method of Qualls and Johnson (1983) was used to determine the UV output of the low and medium pressure mercury lamps. The intensity was measured at 150 cm from the centroid of the lamps.

The low pressure mercury lamps were from Voltarc Tubes Inc., type G36T6L. Three of these lamps were burned for 100 hours before measurements were taken.

One of the 2000 Watt medium pressure mercury lamps were from Voltarc Tubes Inc. Two of the 2000 Watt medium pressure mercury lamps were from W.C. Heraeus.

3. Results and Discussion

The UV light output of the low and medium pressure mercury lamps are summarized in Table 5. The average output of UV light by the 2000 W medium pressure mercury lamps as measured by the point source summation method with the SEE240 sensor is 52.2 watts (Standard Deviation = 1.9). This can be converted to the germicidal power of the low pressure mercury lamp by multiplying by 3.6. The results from Phase 1 showed that each watt of UV light from the medium pressure mercury lamp was equivalent to 3.6 watts of UV light from a low pressure mercury lamp when wastewater from Greenway was being disinfected. The 2000 watt medium pressure mercury lamp has the equivalent of 188 watts of UV light from a low pressure mercury lamp.

The average output of UV light from the low pressure mercury lamps (G36T6L) after 100 hours of burning was 13.2 watts (Standard Deviation = 0.5) as measured by the point source summation method.

One - 2000 watt medium pressure mercury lamp is equivalent to 14.2 low pressure mercury lamps (G36T6L) when effluent from Greenway was being disinfected.

The total output of the two types of lamps as measured by the point source summation method can be used to calculate the flow rates for the various wastewaters. These flow rates are obtained by dividing the total UV output by the dose of UV light required per millilitre of effluent and then converting the answer to litres per minute.

Table 5: UV light output of the medium and low pressure mercury lamps as measured by the point source summation method.

Lamp Type	Watts
Medium Pressure	
Heraeus 1	52.6
Heraeus 2	53.9
Voltarc	50.1
Low Pressure	
G36T6L # 1	12.6
# 2	13.6
# 3	13.5

The flow rates are shown in Table 6 for the various wastewaters. From this Table it can be seen that the flow rates are extremely variable between the various wastewaters. This is a result of the variations in suspended solids, UV transmission and the initial numbers of fecal coliforms. This data on flow rates for a 2000 watt medium pressure mercury lamp will be used to build a UV unit with three different water layers. This UV unit is described in Phase 3. This UV unit will be tested with raw effluent at flow rates of 482, 241 and 120 litres per minute and with primary effluent at flow rates of 1044, 522 and 261 litres per minute.

4. Conclusions

1. Using the point source summation method, the 2000 watt medium pressure mercury lamp produced 52.2 watts of UV light at 254 nm and the low pressure mercury G36T6L lamp put out 13.2 watts of UV light at the same wavelength.

2. The flow rates for the various wastewaters are quite variable due to the differences in suspended solids, UV transmission and numbers of fecal coliforms. Each wastewater should be characterized before being treated with UV light. This characterization should include: suspended solids, UV transmission, level of fecal coliforms and a survival curve of the fecal coliforms.

Table 6: The flow rates of the low and medium pressure lamps for the various wastewaters

Wastewater	Fecal Coliform Limit	Flow Rate (L/min) 2000W Medium Pressure	Flow Rate (L/min) G36T6L Low Pressure
Raw	3 Log Decrease	241	19
	200 per 100 mL	Not Reached	
Primary	3 Log Decrease	522	32
	200 per 100 mL	149	9
Secondary	3 Log Decrease	Not Reached	
	200 per 100 mL	522	32
12.5% Raw: 87.5% Secondary	3 Log Decrease	142	11
	200 per 100 mL	116	9
25% Raw: 75% Secondary	3 Log Decrease	196	14
	200 per 100 mL	224	18
50% Raw: 50% Secondary	3 Log Decrease	348	25
	200 per 100 mL	174	11
Raw Ingersoll	3 Log Decrease	64	8
	200 per 100 mL	Not Reached	

PHASE 3: CONTINUOUS FLOW TESTING OF THE MEDIUM PRESSURE MERCURY LAMP

1. Introduction

Liquids with a low UV transmission and/or high suspended solids must be thoroughly mixed as they pass through a UV unit so that each microorganism is subjected to a maximum dose of UV light. Table 2 shows that raw and primary effluent have a low UV transmission and high suspended solids compared to secondarily treated wastewater. A UV unit containing a 2000 watt medium pressure lamp was built with three different water layers to determine the effect of water depth and flow rate on the disinfection of raw and primary wastewater.

2. Design Specifications and Rationale for the Continuous Flow Reactor

Of the wastewaters examined during Phase 1 of this study, two were chosen for the continuous flow study and these were primary and raw effluent from Greenway Wastewater Treatment Plant in London, Ontario, Canada. These effluents would represent low quality wastewaters with and without sedimentation.

The proposal for the project called for mechanical mixing of the wastewater as it passed by the UV lamp but because of the high flow rates this was substituted with three different water layers around the UV lamp. The UV unit was built with a long inlet and smooth surfaces and curves to minimize the dead corners as the wastewater passed from one water layer to the next. The three water layers were built as one unit to minimize the effect of having three different UV units. The water layers could be studied at the same flow rate in rapid succession to reduce the effect of changes in the wastewater quality.

The UV unit was built around the 2000 watt medium pressure mercury lamp which was used in Phase 1 of this study. This eliminated any changes in the lamp from one phase of the study to another. The UV system was built so that the lamp could be quickly moved without being shut off from one water layer to the next to minimize changes in the effluent and flow rates.

Phase 2 showed that the design flow rate for the raw effluent was 241 litres per minute and for the primary effluent it was 522 litres per minute. This was equivalent to a UV dose of 13mW. sec/mL for the raw effluent and 6mW. sec/mL for the primary effluent.

3. Materials and Methods

A UV unit (Figure 16) was built with three different water layers and a movable 2000 watt medium pressure mercury lamp.

Raw or primary effluent was pumped from the Greenway Wastewater Treatment Plant in London, Ontario, Canada through the UV unit at a the flow rates shown in Figures 17-28. These flow rates varied from 110 L/min to 796 L/min. The average flow rate was kept as close as possible to the optimum flow rate shown in Table 6 for raw and primary effluent. The flow rate was measured with a stopwatch and 400 litre reservoir.

The UV unit was operated in a vertical position and the effluent was pumped into the bottom of the system. After the initial minimum flow rate was set, the lamp was turned on and allowed to burn until the amperage of the lamp stabilized.

The lamp was moved by pulling a marked wire which protruded from top and bottom of the UV unit. The marked wire positioned the UV lamp in the middle of each water layer.

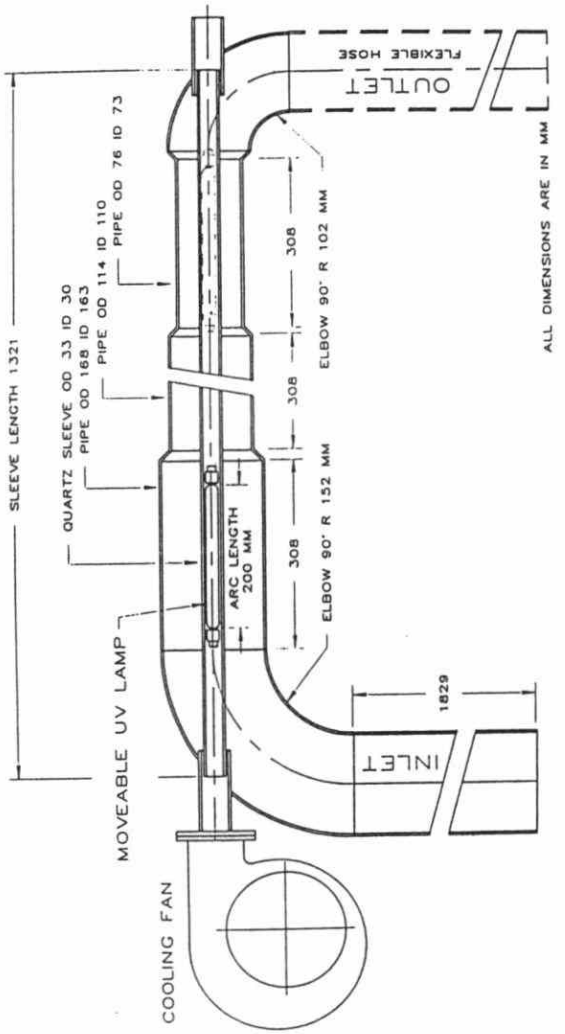


Figure 16: A schematic diagram of the continuous flow UV unit with three different water layers and a moveable UV lamp.

At the beginning of each day's run, a 3.25 kg bottle of analytical reagent grade nitric or hydrochloric acid (British Drug House, Toronto, Canada) was used to clean the quartz sleeve. The acid and water were poured into the UV unit until the quartz sleeve was submerged and then the UV system was gently rocked to mix the acid and the water. A visual inspection showed that this procedure cleaned the quartz sleeve.

Each water layer was tested at one flow rate and then the UV lamp was turned off and the flow rate changed.

Two samples were collected at each flow rate for every water layer. One was immediately put on ice in the dark and the second sample was subjected to sunlight according to the method of Whitby et al. (1984).

Each sample was analyzed for UV transmittance at a wavelength of 254 nm.

The total suspended solids of each wastewater was analyzed according to Method 209C in the 16th Edition of Standard Methods for the Examination of Water and Wastewater (American Public Health Association, 1985).

The fecal coliforms were measured by the membrane filtration method (Ontario Ministry of the Environment, 1984).

4. Results and Discussion

a. Raw Effluent

The level and fraction survival of the fecal coliforms in the raw effluent after irradiation with the 2000 watt medium pressure mercury lamps, three different water layers and various flow rates are shown in Figures 17-22. Each Figure shows the level or fraction survival of the fecal coliforms before and after three hours in the sunlight.

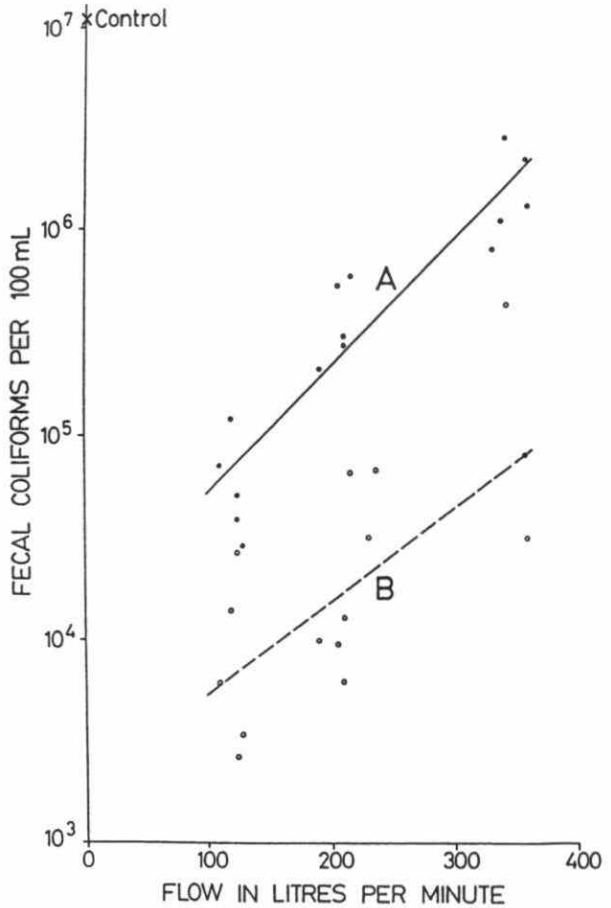


Figure 17: The effect of the two centimetre water layer of the continuous flow UV reactor on the number of fecal coliforms in raw effluent after (A) and before (B) photoreactivation.

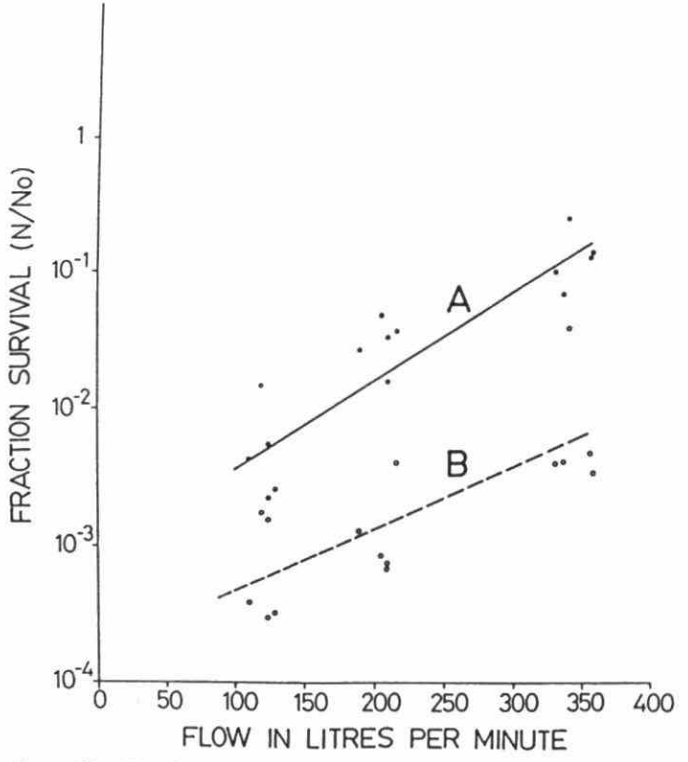


Figure 18: The effect of the two centimetre water layer of the continuous flow UV reactor on the fraction survival of the fecal coliforms in raw effluent after (A) and before (B) photoreactivation.

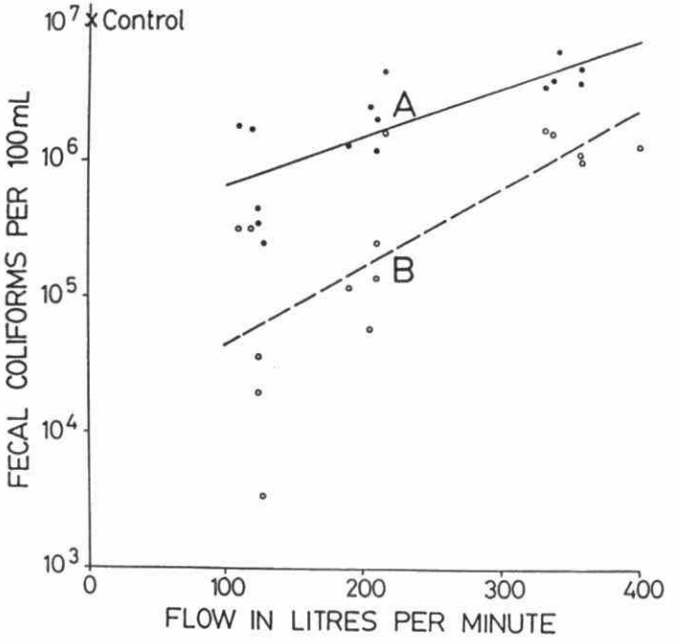


Figure 19: The effect of the 3.85 centimetre water layer of the continuous flow UV reactor on the number of fecal coliforms in raw effluent after (A) and before (B) photoreactivation.

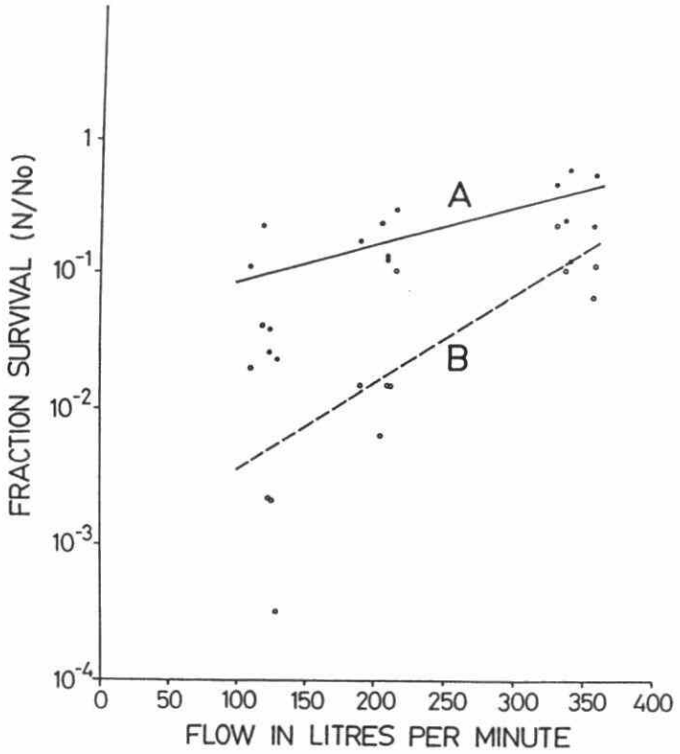


Figure 20: The effect of the 3.85 centimetre water layer of the continuous flow UV reactor on the fraction survival of the fecal coliforms in raw effluent after (A) and before (B) photoreactivation.

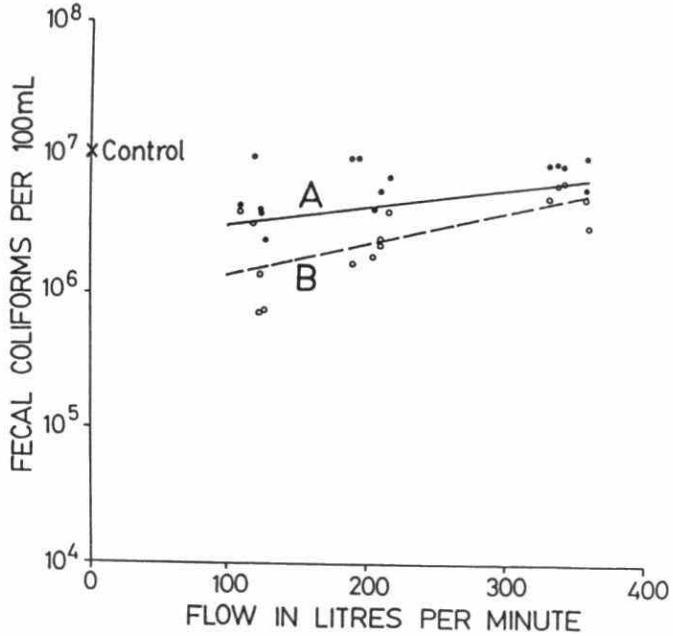


Figure 21: The effect of the 6.5 centimetre water layer of the continuous flow UV reactor on the number of fecal coliforms in raw effluent after (A) and before (B) photoreactivation.

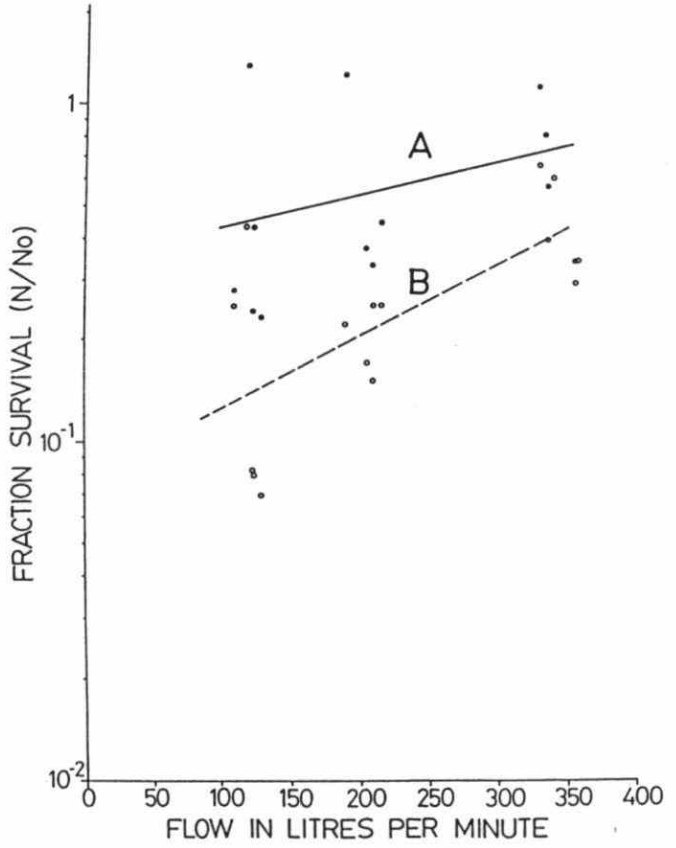


Figure 22: The effect of the 6.5 centimetre water layer of the continuous flow UV reactor on the fraction survival of the fecal coliforms in raw effluent after (A) and before (B) photoreactivation.

The unfiltered raw effluent had a percent transmission of 12.7 (SD=1.7) at a wavelength of 254 nm. The level of suspended solids in the raw effluent was 179 mg/L (SD=41.2).

The dose of UV light in the continuous flow reactor can be calculated by dividing the germicidal wattage of the lamp by the flow rate in millilitres per second.

The total germicidal output of the 2000 W medium pressure lamp was 52.2 watts as measured in Phase 2. Ten percent of this output was subtracted for loses through the quartz sleeve. The dose of UV light in the continuous flow reactor at the slowest flow rate (110 L/min) was 26mW. sec/mL and 7mW. sec/mL at the highest flow rate (399 L/min). The experiments with the collimated beam showed that a dose of 13mW. sec/mL was required for a three logarithm reduction of the fecal coliforms without photoreactivation.

When the above doses of UV light are compared with those in the experiments with the collimated beam (Phase 2), the continuous flow reactor was unable to reduce the fecal coliforms to the same concentration or reach the same fraction survival.

The dry summer in London, Ontario, Canada had increased the suspended solids by 48 percent and decreased the transmission of the UV light by 54 percent. The increased concentration of suspended solids shields more fecal coliforms from the UV radiation and thus the limiting number of microorganisms which can be killed increases.

Mixing of the effluent is more complete during the experiments with the collimated beam and this will result in a greater kill of the fecal coliforms when the same volume of fluid is subjected to an identical dose of UV light.

A three logarithm kill of the fecal coliforms was obtained with flows of less than 172 litres per minute with the two centimeter water layer and 2000 watt medium pressure lamp. After photoreactivation, a three logarithm kill of the fecal coliforms was not obtained at any of the tested flow rates. Extrapolating the data beyond the tested flow rates may be invalid because the dose response curve is not linear over the entire range of UV doses. This is illustrated by the dose response curves in Phase 1 (Figures 1-8). If the response is linear, then the two centimeter water layer produces a three logarithm kill after photoreactivation at a flow rate of 14 litres per minute and the water layer with a depth of 3.85 cm produces a three logarithm kill without photoreactivation at a flow rate of 11 litres per minute.

As the kill of the fecal coliforms in the raw effluent increased there was a general increase in the degree of photoreactivation and this is in agreement with the research reviewed by Rupert (1964).

b. Primary Effluent

The level and fraction survival of the fecal coliforms in the primary effluent after irradiation with the 2000 watt medium pressure mercury lamp at various flow rates through three different water layers are shown in figures 23-28. Each Figure shows the level or fraction survival of the fecal coliforms before and after three hours in the sunlight.

The unfiltered primary effluent had a percent transmission of 27.1 (SD=1.7) at a wavelength of 254 nm. The level of suspended solids in the primary effluent was 45 mg/L (SD=6.7). The percent transmission was almost identical to that during the experiments with the collimated beam. The level of suspended solids was 27 percent less during the continuous flow studies.

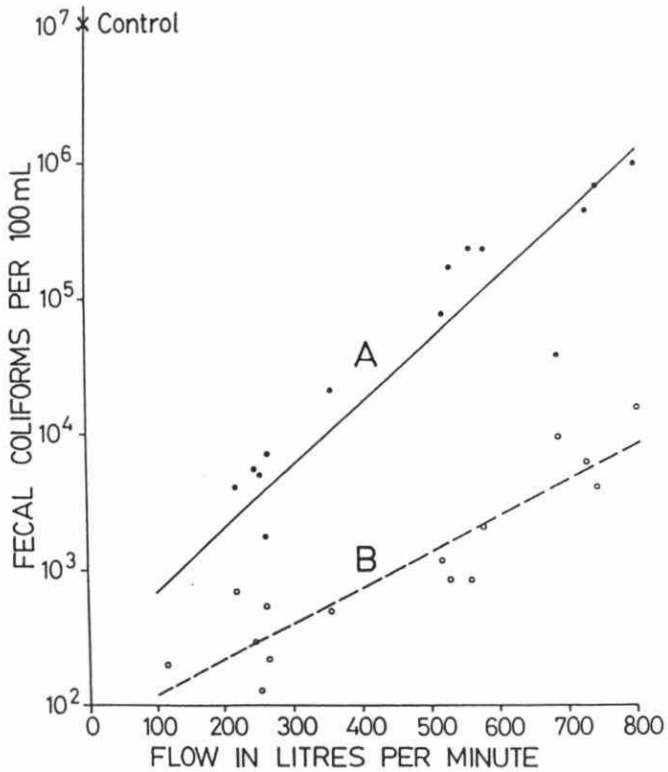


Figure 23: The effect of the two centimetre water layer of the continuous flow UV reactor on the number of fecal coliforms in primary effluent after (A) and before (B) photoreactivation.

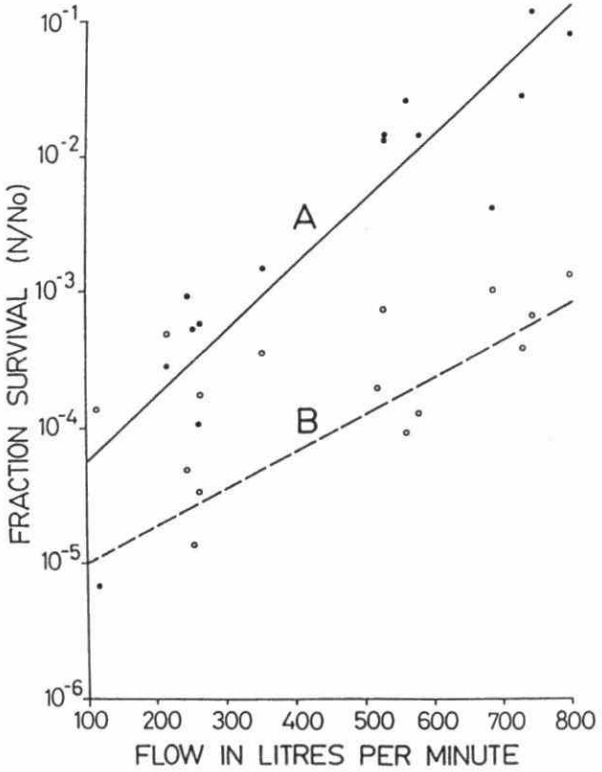


Figure 24: The effect of the two centimetres water layer of the continuous flow UV reactor on the fraction survival of the fecal coliforms in primary effluent after (A) and before (B) photoreactivation.

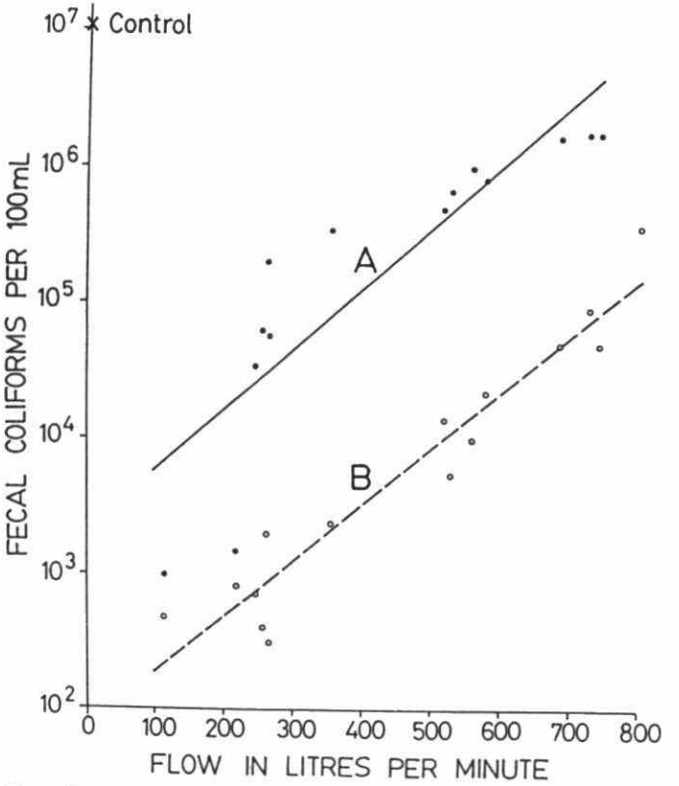


Figure 25: The effect of the 3.85 centimetre water layer of the continuous flow UV reactor on the number of fecal coliforms in primary effluent after (A) and before (B) photoreactivation.

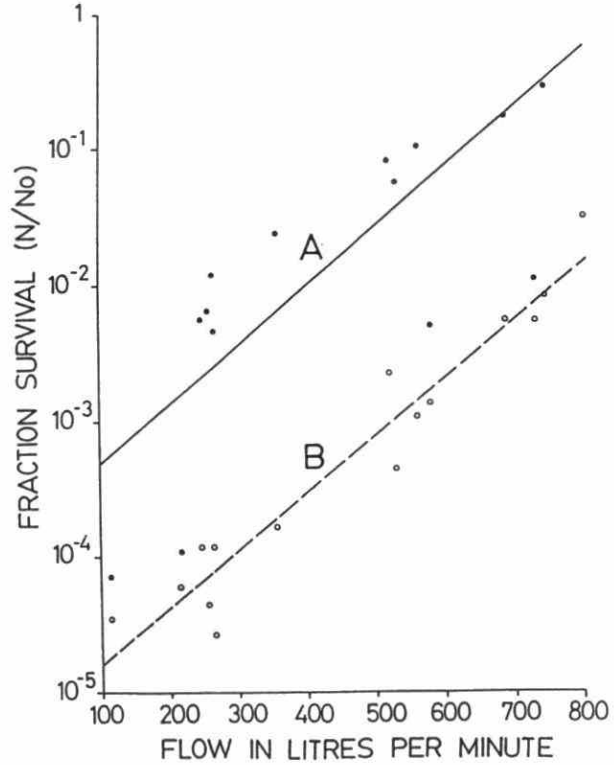


Figure 26: The effect of the 3.85 centimetre water layer of the continuous flow UV reactor on the fraction survival of the fecal coliforms in primary effluent after (A) and before (B) photoreactivation.

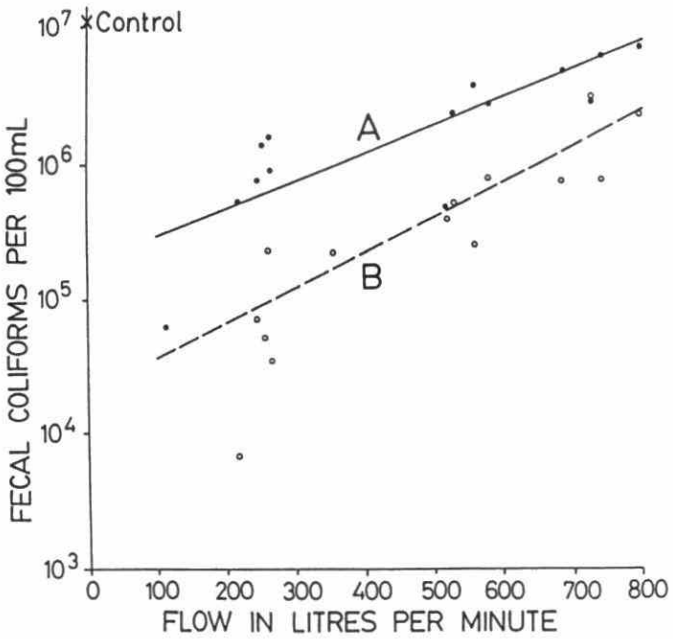


Figure 27: The effect of the 6.5 centimetre water layer of the continuous flow UV reactor on the number of fecal coliforms in primary effluent after (A) and before (B) photoreactivation.

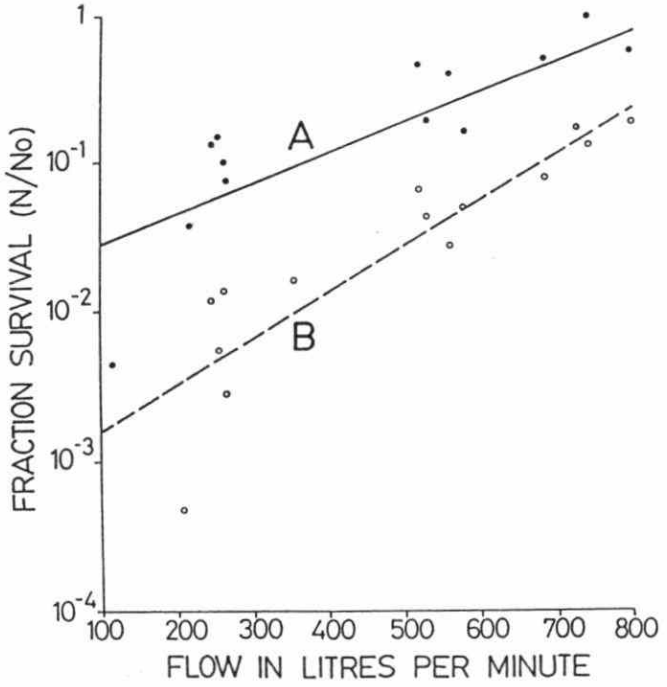


Figure 28: The effect of the 6.5 centimetre water layer of the continuous flow UV reactor on the fraction survival of the fecal coliforms in primary effluent after (A) and before (B) photoreactivation.

The dose of UV light in the continuous flow reactor was calculated in the same manner as it was for the raw effluent. The dose of UV light in the continuous flow reactor at the minimum flow rate (113 L/min) was 25 mW. sec/mL and 3.5 mW. sec/mL at the maximum flow rate (796 L/min). The experiments with the collimated beam in Phase 1 showed that a dose of 6 mW. sec/mL produced a three logarithm kill of the fecal coliforms without photoreactivation.

A comparison of the UV dose response between the continuous flow reactor and the experiments with the collimated beam showed that the two centimeter water layer attained the same or a better kill of the fecal coliforms at the high and low flow rates. Because the two sets of primary effluents were more closely related than the raw effluents, the mixing occurring during the flow of water through the two centimeter water layer must be similar to that occurring in the dishes used during the experiments with the collimated beam.

The 38.5 mm water layer also attained a three logarithm kill of the fecal coliforms before photoreactivation at the lowest flow rate which was tested. None of the combinations of flow rate and water layer produced a three logarithm kill of the fecal coliforms.

The data from the 65 mm water layer can be extrapolated to obtain the flow rate which produces a three logarithm kill of the fecal coliforms. This flow rate should be used with caution because the dose response curve is not linear over the entire UV dose range as shown in Figures 2-8. Without photoreactivation, the flow rate was 34 litres per minute for the 65 mm water layer.

Photoreactivation resulted in an average 1.3 logarithm increase in the fraction survival of the fecal coliforms in primary effluent. The average increase due to photoreactivation of the fecal coliforms in the raw and primary effluent after UV irradiation was one logarithm. This is similar to other studies

with UV irradiated fecal coliforms in wastewater (Whitby et al, 1985 and 1984; Scheible and Bassell, 1981 and Bohm et al., 1982). There was no consistent increase or decrease in the degree of photoreactivation of the fecal coliforms in the primary effluent with a change in flow rate or water layer.

Conclusions

1. The two centimeter water layer with the 2000 W medium pressure mercury lamp approached the kill of the fecal coliforms obtained with the experiments with the collimated beam in Phase 1.

2. Mixing of effluents with high concentrations of suspended solids and low UV transmission is essential because each microbe must receive a minimum dose of UV light to be destroyed. Only the two centimeter water layer approached the proper mixing regime with raw and primary effluent.

3. A dose response curve of the fecal coliforms in low quality wastewaters should be prepared using static and continuous flow methods. The differences between the effluents and the results of the experiments with the collimated beam and the continuous flow reactor show the need for these types of experiments.

4. The UV equipment must be built for the worst conditions because a change in the quality of the effluent can dramatically effect the performance of the UV unit.

5. The continuous flow reactor was able to reach a three logarithm kill of the fecal coliforms with and without photoreactivation when treating primary effluent but only without photoreactivation when treating raw effluent.

COST ANALYSIS OF UV IRRADIATION FOR DISINFECTING LOW QUALITY WASTEWATERS

1. Introduction

An analysis of capital, operating and maintenance costs of disinfecting primary and raw effluents with medium pressure mercury lamps was undertaken to compare this disinfection alternative with chlorination and UV irradiation with low pressure mercury lamps.

2. Design Specification

a. Low Quality Wastewaters

Very little information is available which describes the UV transmission or concentration of suspended solids in low quality wastewaters. The simulated combined sewer overflow used by Zukovs et al. (1986) had a UV transmission at a wavelength of 254 nm of 2.8 percent per centimeter pathlength and the level of suspended solids was 187 mg/L. The primary effluent studied by Scheible et al. (1985) had a UV transmission at a wavelength of 254 nm of 55 percent per centimeter and the concentration of suspended solids was 80 mg/L. A review of the literature by Zukovs et al. (1986) showed that combined sewer overflow had levels of suspended solids between 80 and 274 mg/L.

Due to the above variations in low quality wastewaters, costs were developed for raw and primary effluent with the following UV transmissions at a wavelength of 254 nm and level of suspended solids. The raw effluent had a minimum UV transmission at a wavelength of 254 nm of 13 percent and a maximum concentration of suspended solids of 180 mg/L. The primary effluent had a minimum UV transmission at a wavelength of 254 nm of 27 percent and a maximum concentration of suspended solids of 45 mg/L.

b. Disinfection Standard

Phase 1 of this project showed that it was not practical to strive for a four logarithm kill of the fecal coliforms. Kollar et al. (1986) estimated their UV irradiation and chlorination costs with a four logarithm reduction of fecal coliforms but the results in this study show that this is not possible with UV irradiation.

A three logarithm kill of the fecal coliforms was obtained in the experiments with the collimated beam (Phase 1) and the continuous flow reactor (Phase 3). The UV equipment was costed to reach a three logarithm kill of the fecal coliforms.

If a three logarithm kill of the fecal coliforms after photoreactivation is required then it is not practical to treat raw effluent but it is possible to treat primary effluent. In raw effluent none of the combinations of flow rate and water layer reached a three logarithm kill of the fecal coliforms after photoreactivation. In primary effluent a three logarithm kill of the fecal coliforms was obtained after photoreactivation.

3. Disinfection Facilities

a. Introduction

UV equipment was designed for three different peak flow rates: 5,000, 50,000 and 500,000 m^3/day. The UV systems were designed for raw effluent without photoreactivation of the three logarithm kill of the fecal coliforms and for primary effluent with a three logarithm kill of the fecal coliforms before and after photoreactivation.

This cost analysis was for the capital, operating and maintenance cost for the UV equipment only and not the flow meters, buildings, cement work, etc.

b. Raw Effluent

The basic unit for estimating capital costs was a medium pressure mercury lamp and its associated hardware such a quartz sheath, ballast, starter, lamp supports, control box, cooling equipment and stainless steel shell. The capital costs for the UV equipment are shown in Table 7.

The operating and maintenance costs are shown in Table 7. The lamp replacement costs were estimated to be $300.00 per UV lamp. The UV lamps must be replaced every 5000 hours. Kollar et al. (1986) assumed that these facilities would operate only when required during the period from March to November, with total annual operating time assumed to be 250 hours. The lamp replacement frequency was assumed to be once every twenty years for the medium pressure mercury lamps.

After each use, the quartz sheaths should be acid washed to remove any deposits. A ten percent solution of phosphoric acid can be recirculated through the UV unit. This solution can be stored for further use. The estimated time required for cleaning was 4.5 to 8 hours. The capital cost for the inplace cleaning systems is shown in Table 8. The wage rate for a worker for the Ontario Ministry of the Environment is $13.41 per hour plus 25 percent benefits.

The power costs are shown in Table 7.

Table 7: Estimated costs for UV disinfection of raw effluent without photoreactivation of the fecal coliforms

	Flow Rate (m^3/d)		
Cost Component	5,000	50,000	500,000
Capital UV System	96,000	768,000	7,680,000
In Place Cleaning	14,000	22,000	150,000
Total Capital ($ 1988)	110,000	790,000	7,830,000
Operation and Maintenance			
Power (6¢/kwh)	2304	23,040	230,400
Labour ($16.76/h)	1676	2,095	3,352
Lamps	240	2,400	24,000
Chemicals	24	241	2,410
Total Operation and Maintenance ($/year 1988)	4,464	27,776	260,162

c. Primary Effluent

The two centimeter water layer was able to produce a three logarithm kill of the fecal coliforms with and without photoreactivation at flow rates of 360 and 825 litres per minute per UV lamp. The 3.85 centimeter water layer was able to produce a three logarithm kill fo the fecal coliforms without photoreactivation at a flow rate of 520 litres per minute per UV lamp. Extrapolation of the data with the 3.85 centimeter water layer showed that a three logarithm kill of the fecal coliforms after photoreactivation could be obtained at a flow rate of 175 litres per minute per UV lamp.

A flow rate of 370 and 147 litres per minute per UV lamp was used for estimating the number of lamps for a three logarithm kill of the fecal coliforms before and after photoreactivation, respectively. This is the average flow rate between the 2 and 3.85 centimeter water layer decreased by 45 percent for lamp aging.

The capital costs for the UV equipment are shown in Tables 8 and 9.

The operating and maintenance costs for primary effluent were estimated in an identical fashion to that of the raw effluent and are shown in Tables 8 and 9.

The annualized use-costs for UV disinfection of raw and primary effluent presented in Table 10 are based on a 20 year period and a discount rate of 7% as was used by Kollar et al. (1986).

Table 8: Estimated costs for UV disinfection of primary effluent without photoreactivation of the fecal coliforms

	Flow Rate (m^3/d)		
Cost Component	5,000	50,000	500,000
Capital UV System	18,000	144,000	1,440,000
In Place Cleaning	7,000	11,000	75,000
Total Capital ($ 1988)	25,000	155,000	1,515,000
Operation and Maintenance			
Power (6¢/kwh)	432	4,320	43,200
Labour ($16.76/h)	1,676	1,676	2,095
Lamps	45	450	4,500
Chemicals	5	52	520
Total Operation and Maintenance ($/year 1988)	2,158	6,498	50,315

Table 9: Estimated costs for UV disinfection of primary effluent with photoreactivation of the fecal coliforms

	Flow Rate (m^3/d)		
Cost Component	5,000	50,000	500,000
Capital UV System	36,000	288,000	2,880,000
In Place Cleaning	14,000	22,000	150,000
Total Capital ($ 1988)	50,000	310,000	3,030,000
Operation and Maintenance			
Power (6¢/kwh)	864	8,640	86,400
Labour ($16.76/h)	1676	1,676	2,095
Lamps	90	900	9,000
Chemicals	9	86	860
Total Operation and Maintenance ($/year 1988)	2,639	11,302	98,355

Table 10: Estimated Use-Cost of Disinfecting Primary and Raw Effluents with Medium Pressure Mercury Lamps

Cost Component ($1988)	Flowrate (m^3/d) 5000	50,000	500,000
Raw, No Photoreactivation	$2.97/m^3/d/yr$	2.05	2.00
Primary, No Photoreactivation	0.90	0.42	0.39
Primary, Photoreactivation	1.47	0.81	0.77

The estimated use-costs of disinfection simulated combined sewer overflow and chemically treated primary effluent with low pressure mercury lamps are shown in Table 11. These costs were from the study of Kollar et al. (1986). To compare the two types of UV lamps only the capital and operating costs of the UV equipment itself were considered.

To compare UV disinfection with chlorination/dechlorination only the contact chamber, chemical storage tanks, pumps, piping, flow meter, injector system, evaporator, operation and maintenance were considered in the use-cost estimate from the work of Kollar et al. (1986) and these use-costs are shown in Table 12. The majority of the other capital costs are common to all of the forms of disinfection.

Disinfection of low quality wastewaters with UV light from medium pressure mercury lamps or with chlorination is lower than with low pressure mercury lamps.

Table 11: Estimated Use-Cost of Disinfecting Simulated Combined Sewer Overflow and Chemically Treated Primary Effluent with Low Pressure Mercury Lamps

Cost Component ($1985)	Flowrate (m^3/d) 5000	50,000	500,000
Simulated Combined Sewer Overflow	13.93/m^3/d/yr	12.94	12.04
Chemically Treated Primary Effluent	11.70	10.87	10.12

Table 12: Estimated Use-Cost of Disinfecting Simulated Combined Sewer Overflow and Chemically Treated Primary Effluent with Chlorination/Dechlorination and Chlorination, Respectively

Cost Component ($1985)	Flowrate (m^3/d) 5000	50,000	500,000
Simulated Combined Sewer Overflow	2.48/m^3/d/yr	1.36	1.04
Chemically Treated Primary Effluent	1.26	0.37	0.19

PROJECT CONCLUSIONS

1. Each type of wastewater required a different dose of UV light to reach the required level of disinfection due to the UV transmission, suspended solids and the relationship of the fecal coliforms with the solids.

2. To design a UV system for low quality wastewaters a series of survival curves should be prepared using the method with a collimated beam to determine whether the disinfection standard can be attained and the proper dose of UV light which is required to reach this disinfection standard. These results should be confirmed with continuous flow studies with a scale model of the projected UV equipment.

3. Medium pressure mercury lamps can reduce the fecal coliforms in raw and primary effluent by three logarithms in a static and continuous flow situation.

4. A use-cost comparison of UV disinfection of raw and primary effluent with medium pressure mercury lamps with that with low pressure mercury lamps showed that capital, operating and maintenance costs were lower with the former lamps.

5. Treatment of primary effluent by medium pressure mercury lamps without photoreactivation of the fecal coliforms was use-cost competitive with the chlorination of chemically treated primary wastewater. Chlorination and chlorination/dechlorination were lower in cost for the other effluents.

6. UV disinfection of low quality wastewaters may be an alternative to chlorination when the ecological considerations are taken into account such as the production of harmful chloro-organic compounds and residual of chlorine on the aquatic biota.

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